A Stepwise Efficiency Improvement DEA Model for Airport Operations with Fixed Production Factors

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Abstract

In the spirit of the deregulation movement, Japan is also faced with an "Asia Open Sky" agreement which favours aviation liberalization in international services. This means an end to Japan's aviation policy of isolation. In association with this policy change, also environmental concerns grew increasingly severe for small and local regional airports. Consequently, there is a need for an objective and transparent analysis of the performance and efficiency of airport operations in Japan.

A standard tool to judge the efficiency of such business activities is Data Envelopment Analysis (DEA). In the past years, much progress has been made to extend this approach in various directions. Interesting examples are the Distance Friction Minimization (DFM) model and the Context-Dependent (CD) model.

The DFM model is based on a generalized distance friction function and serves to improve the performance of a Decision Making Unit (DMU) by identifying the most appropriate movement towards the efficiency frontier surface. Standard DEA models use a uniform proportional input reduction (or a uniform proportional output increase) in the improvement projections, but the DFM approach aims to enhance efficiency strategies by introducing a weighted projection function. This approach may address both input reduction and output increase as a strategy of a DMU. Likewise, the CD model yields efficient frontiers at different levels, while it is based on a level-by-level improvement projection. The Stepwise DFM model described in the present study is an integration of the original DFM and the CD model in order to design a stepwise efficiency-improving projection model for a conventional DEA. In general, a DEA model – and neither the mix of the DFM-CD model – does not take into account a non-controllable or a fixed factor. Such a non-controllable of fixed factor may refer to a production (input) factor that cannot be flexibly adjusted in the short run.

In our study the newly integrated Stepwise DFM-CD model will be extended with a fixed factor model in order to adapt the DEA performance model to realistic circumstances and requirements in an efficiency improvement projection. After the description of the methodology, the above-mentioned stepwise fixed factor projection model is illustrated on the basis of an application to the efficiency analysis of airport operations in Japan in light of the above mentioned contextual changes in aviation policy.

Keywords: Data Envelopment Analysis (DEA), Stepwise Projection, Distance Friction Minimization, Context-Dependent Model, Fixed Factor, Airport Operations

1. Introduction

In Japan, it is faced with an “Asia Open Sky” that is aviation liberalization in international service. It is meaning end Japan's aviation policy of isolation. In association with this policy changeover, management environment grow increasingly severe for small and local regions airport. It is a need for an objective analysis of performance and efficiency for Airport operations.

A standard tool to judge the efficiency of such agencies is Data Envelopment Analysis (DEA). Seiford (2005) mentions some 2800 published articles on DEA. This large number of studies shows that comparative efficiency analysis has become an important topic.

DEA was developed to analyze the relative efficiency of Decision Making Unit (DMU), by constructing a piecewise linear production frontier, and projecting the performance of each DMU onto the frontier. A DMU that is located on the frontier is efficient, while a DMU that is not on the frontier is inefficient. An inefficient DMU can become efficient by reducing its inputs or increasing its outputs. In the standard DEA approach, this is achieved by a uniform reduction in all inputs (or a uniform increase in all outputs). But in principle, there are an infinite number of improvements to reach the efficient frontier, and hence there are many solutions for a DMU to enhance efficiency. The existence of an infinite number of solutions to reach the efficient frontier has led to a stream of literature on the integration of DEA and Multiple Objective Linear Programming (MOLP), which was initiated by Golany (1988).

Suzuki and Nijkamp (2010a) proposed a Distance Friction Minimization (DFM) model that is based on a generalized distance friction function and serves to improve the performance of a DMU by identifying the most appropriate movement towards the efficiency frontier surface. This approach may address both an input reduction and an output increase as a strategy of a DMU.

A general efficiency-improving projection model including a DFM model is able to calculate either an optimal input reduction value or an output increase value to reach an efficient score of 1.0, even though in reality this may be hard to achieve, i.e., it is nearly impossible that one small local regions airport completely exert subequal efficiency with one large metropolitan regions airport (Tokyo HANEDA or Osaka ITAMI).

Seiford and Zhu (2003) developed a gradual improvement model for an inefficient DMU. This ‘Context-Dependent (CD)’ DEA has an important merit, as it aims to reach a stepwise improvement through successive levels towards the efficiency frontier. Suzuki and Nijkamp (2010b) proposed a Stepwise DFM model that is an integration of the DFM and CD model in order to design a stepwise efficiency-improving projection model for a conventional DEA. However, this model doesn't corresponding to a non-controllable or a fixed factor.

In this study newly integrated the Stepwise DFM model and a fixed factor model which proposed by Suzuki and Nijkamp (2011) in order to adapt a realistic circumstance and requirement in an efficiency improvement projection.

The above-mentioned stepwise fixed factor projection model is illustrated on the basis of an application to the efficiency analysis of airport operations in Japan.

2. Efficiency Improvement Projection in DEA

The standard Charnes et al. (1978) model (abbreviated hereafter as the CCR-input model) for a given DMU_j $(j=1,\cdots,J)$ to be evaluated in any trial o (where o ranges over 1, 2 …, J) may be represented as the following fractional programming (FP_o) problem:

$$(FP_o) \qquad \max_{v,u} \quad \theta = \frac{\sum_s u_s y_{so}}{\sum_m v_m x_{mo}}$$

$$\text{s.t.} \qquad \frac{\sum_s u_s y_{sj}}{\sum_m v_m x_{mj}} \le 1 \quad (j=1,\cdots,J) \tag{2.1}$$

$$v_m \ge 0,\ \ u_s \ge 0,$$

where θ represents an objective variable function (efficiency score); x_{mj} is the volume of input m (m=1,…, M) for DMU j (j=1,…,J); y_{sj} is the output s (s=1,…,S) of DMU j; and v_m and u_s are the weights given to input m and output s, respectively. Model (2.1) is often called an input-oriented CCR model, while its reciprocal (i.e. an interchange of the numerator and denominator in objective function (2.1), with a specification as a minimization problem under an appropriate adjustment of the constraints) is usually known as an output-oriented CCR model. Model (2.1) is obviously a fractional programming model, which may be solved stepwise by first assigning an arbitrary value to the denominator in (2.1), and then maximizing the numerator.

The improvement projection $(\hat{x}_o, \hat{y}_o)$ can now be defined in (2.2) and (2.3) as:

$$\hat{x}_o = \theta^* x_o - s^{-*} \tag{2.2}$$

$$\hat{y}_o = y_o + s^{+*} \tag{2.3}$$

These equations indicate that the efficiency of (x_o, y_o) for DMU_o can be improved if the input values are reduced radially by the ratio θ^*, and the input excesses s^{-*} are eliminated (see Figure 1). The original DEA models presented in the literature have thus far only focused on a uniform input reduction or a uniform output increase in the efficiency-improvement projections, as shown in Figure 1 (θ^*=OC'/OC).

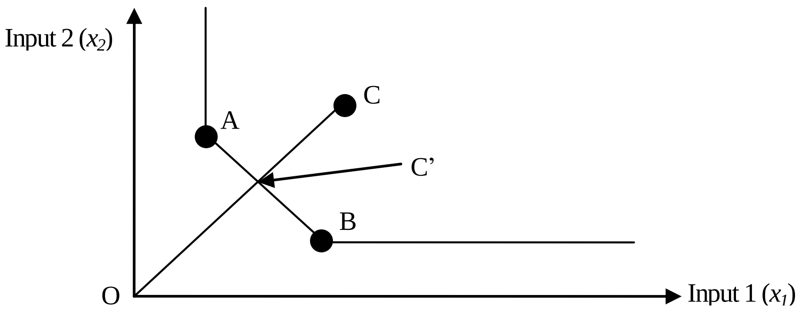

Figure 1 Illustration of original DEA projection in input space

3. The Distance Friction Minimization (DFM) Approach

As mentioned, the efficiency improvement solution in the original CCR-input model requires that the input values are reduced radially by a uniform ratio θ^* (θ^*=OD'/OD in Figure 2).

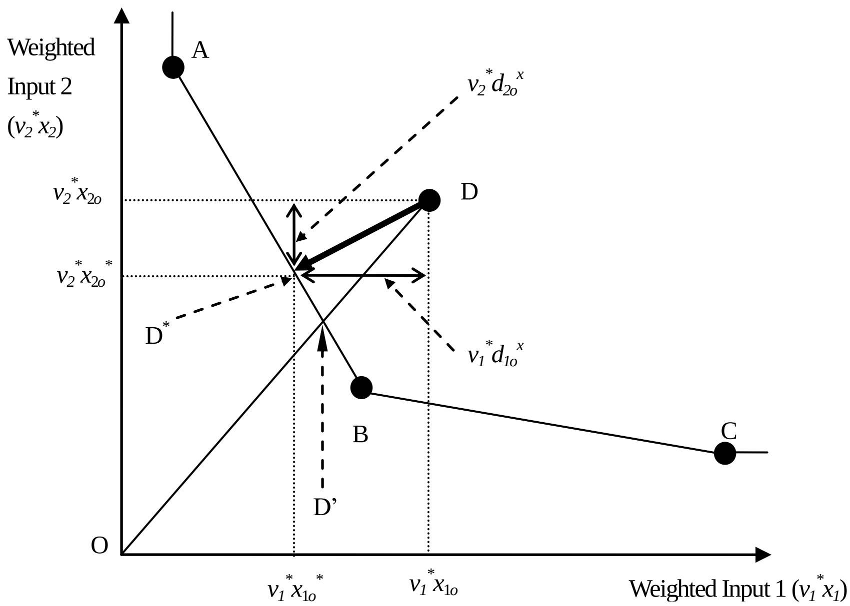

Figure 2 Illustration of the DFM approach (Input- $v_i^* x_i$ space)

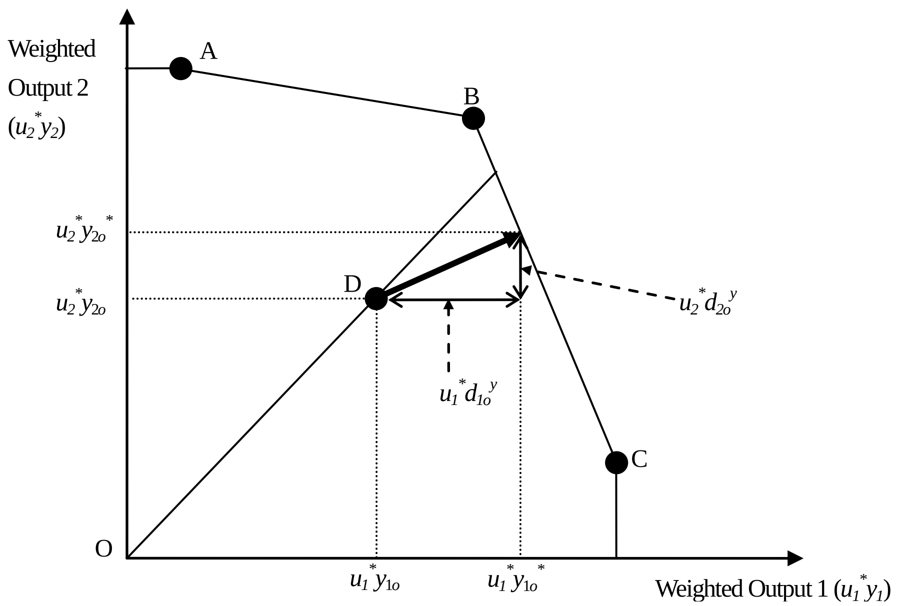

Figure 3 Illustration of the DFM approach (Output - $u_r^* y_r$ space)

The (v^*, u^*) values obtained as an optimal solution for formula (2.1) result in a set of optimal weights for DMU_o.

As mentioned earlier, (v^*, u^*) is the set of most favourable weights for DMU_o, in the sense of maximizing the ratio scale. v_m^* is the optimal weight for the input item *m*, and its magnitude expresses how much in relative terms the item is contributing to efficiency. Similarly, u_s^* does the same for the output item *s*. These values show not only which items contribute to the performance of DMU_o, but also to what extent they do so. In other words, it is possible to express the distance frictions (or alternatively, the potential increases) in improvement projections.

In this study, we use the optimal weights u_s^* and v_m^* from (2.1), and then describe next efficiency improvement projection model. A visual presentation of this new approach is given in Figures 2 and 3.

In this approach a generalized distance friction is deployed to assist a DMU in improving its efficiency by a movement towards the efficiency frontier surface. The direction of efficiency improvement depends of course on the input/output data characteristics of the DMU. It is now appropriate to define the projection functions for the minimization of distance friction by using a Euclidean distance in weighted spaces. As mentioned, a suitable form of multidimensional projection functions that serves to improve efficiency is given by a MOQP model which aims to minimize the aggregated input reduction frictions, as well as the aggregated output increase frictions. Thus, the DFM approach can generate a new contribution to efficiency enhancement problems in decision analysis, by deploying a weighted Euclidean projection function, and at the same time it may address both input reduction and output increase. Here we will only describe the various steps concisely.

First, specify the distance friction function Fr^x and Fr^y by means of (3.1) and (3.2), which are defined by the Euclidean distance shown in Figures 2 and 3. Next, solve the following MOQP by using d^x_{mo} (a reduction of distance for x_{io}) and d^y_{so} (an increase of distance for y_{so}) as minimands in an L_2 metric:

$$\min \ Fr^x = \sqrt{\sum_m \left(v^*_m x_{mo} - v^*_m d^x_{mo}\right)^2} \tag{3.1}$$

$$\min \ Fr^y = \sqrt{\sum_s \left(u^*_s y_{so} - u^*_s d^y_{so}\right)^2} \tag{3.2}$$

s.t.
$$\sum_m v^*_m \left(x_{mo} - d^x_{mo}\right) = \frac{2\theta^*}{1+\theta^*} \tag{3.3}$$

$$\sum_s u^*_s \left(y_{so} + d^y_{so}\right) = \frac{2\theta^*}{1+\theta^*} \tag{3.4}$$

$$x_{mo} - d^x_{mo} \geq 0 \tag{3.5}$$

$$d^x_{mo} \geq 0 \tag{3.6}$$

$$d^y_{so} \geq 0\,, \tag{3.7}$$

where x_{mo} is the amount of input item m for any arbitrary inefficient DMU_o, and y_{so} is the amount of output item s for any arbitrary inefficient DMU_o. The constraint functions (3.3) and (3.4) refer to the target values of input reduction and output augmentation. The fairness in the distribution of contributions from the input and output side to achieve efficiency is established as follows. The total efficiency gap to be covered by inputs and outputs is (1-θ*). The input and the output side contribute according to their initial levels 1 and θ*, implying shares θ*/(1+θ*) and 1/(1+θ*) in the improvement contribution. Hence the contributions from both sides equal (1-θ*)[θ*/(1+θ*)], and (1-θ*)[1/(1+θ*)]. Hence we find for the input reduction target and the output augmentation targets:

Input reduction target: $$\sum_m v^*_m \left(x_{mo} - d^x_{mo}\right) = 1 - \left(1-\theta^*\right) \times \frac{1}{\left(1+\theta^*\right)} = \frac{2\theta^*}{1+\theta^*} \tag{3.8}$$

Output augmentation target:: $$\sum_s u^*_s \left(y_{so} + d^y_{so}\right) = \theta^* + \left(1-\theta^*\right) \times \frac{\theta^*}{\left(1+\theta^*\right)} = \frac{2\theta^*}{1+\theta^*} \tag{3.9}$$

An illustration is given in Figure 4.

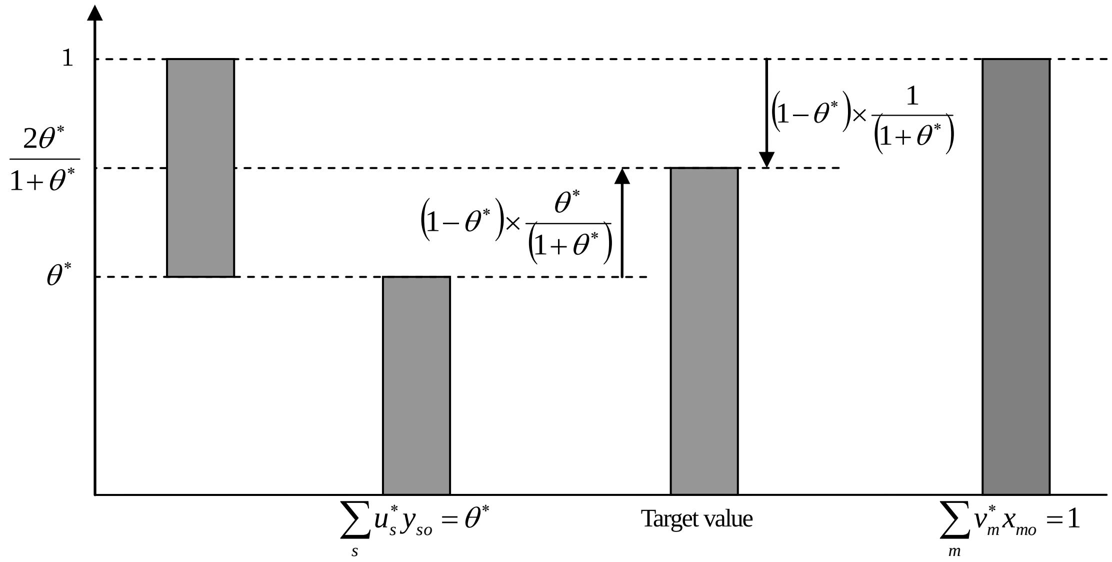

Figure 4 Presentation of 'fair' allocation for the total efficiency gap

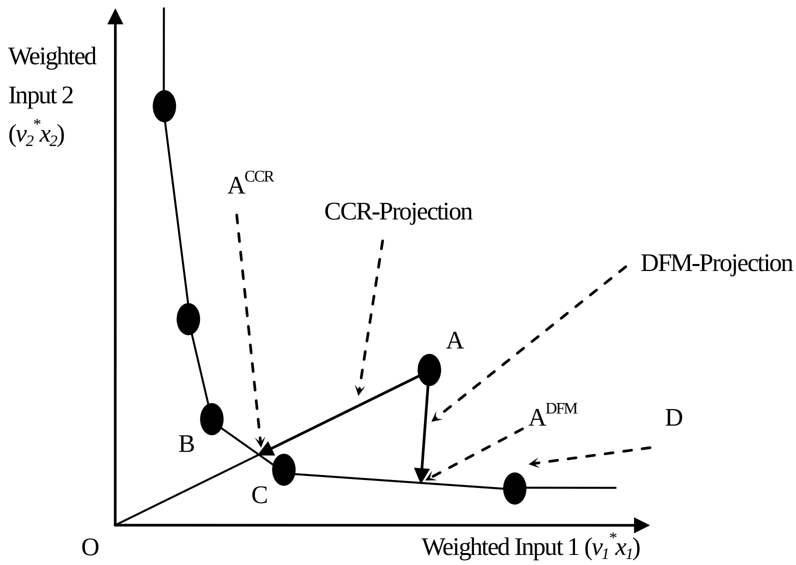

Figure 5 Degree of improvement of DFM and CCR projection in weighted input space

It is now possible to determine each optimal distance d_{mo}^{x*} and d_{so}^{y*} by using the MOQP model (3.1)-(3.7).

The friction minimization solution for an inefficient DMU_o can now be expressed by means of formulas (3.9) and (3.10):

$$x_{mo}^* = x_{mo} - d_{mo}^{x*} \tag{3.9}$$

$$y_{so}^* = y_{so} + d_{so}^{y*} \tag{3.10}$$

By means of the DFM model, it is possible to present a new efficiency-improvement solution based on the standard CCR projection. This means an increase in new options for efficiency-improvement solutions in DEA. The main advantage of the DFM model is that it yields an outcome on the efficient frontier that is as close as possible to the DMU's input and output profile (see Figure 5).

4. A Fixed Factor Model in DFM

We present a version of the DFM model that takes into account the presence of fixed factors. The efficiency improvement projection incorporating a fixed factor (FF) in a DFM model is presented in (4.1)-(4.7):

$$\min \ Fr^x = \sqrt{\sum_{m \in D} \left(v_m^* x_{mo} - v_m^* d_{mo}^x\right)^2} \tag{4.1}$$

$$\min \ Fr^y = \sqrt{\sum_{s \in D} \left(u_s^* y_{so} - u_s^* d_{so}^y\right)^2} \tag{4.2}$$

$$\text{s.t.} \ \sum_{m \in D} v_m^* \left(x_{mo} - d_{mo}^x\right) + \sum_{m \in ND} v_m^* x_{mo} = 1 - \frac{\left(1-\theta^*\right)\left(1 - \sum_{m \in ND} v_m^* x_{mo}\right)}{\left(1 - \sum_{m \in ND} v_m^* x_{mo}\right) + \left(\theta^* - \sum_{s \in ND} u_s^* y_{so}\right)} \tag{4.3}$$

$$\sum_{s \in D} u_s^* \left(y_{so} + d_{so}^y\right) + \sum_{s \in ND} u_s^* y_{so} = \theta^* + \frac{\left(1-\theta^*\right)\left(\theta^* - \sum_{s \in ND} u_s^* y_{so}\right)}{\left(1 - \sum_{m \in ND} v_m^* x_{mo}\right) + \left(\theta^* - \sum_{s \in ND} u_s^* y_{so}\right)} \tag{4.4}$$

$$x_{mo} - d_{mo}^x > 0 \tag{4.5}$$

$$d_{mo}^x \geq 0 \tag{4.6}$$

$$d_{so}^y \geq 0 \tag{4.7}$$

Where the symbol $m \in D$ and $s \in D$ refers to the set of 'discretionary' inputs and outputs; and the symbol $m \in ND$ and $s \in ND$ refers to the set of 'non-discretionary' inputs and outputs.

The meaning of function (4.1) and (4.2) is to consider only the distance friction of discretionary inputs and outputs. The constraint functions (4.3) and (4.4) are incorporated in the non-discretionary factors for the efficiency gap. The target values for input reduction and output augmentation with a 'fair' allocation depend on all total input-output scores and fixed factor situations as presented in Figure

6. The calculated result of (4.3) will then coincide with the calculated result of (4.4).

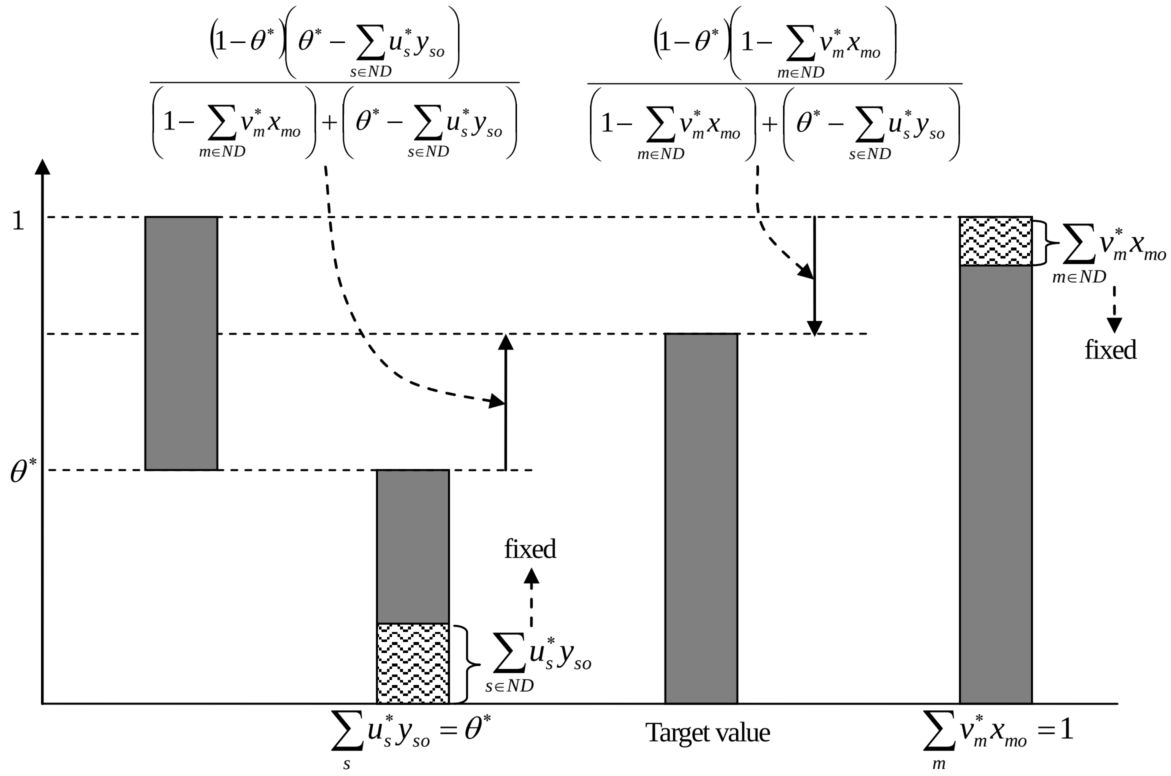

Figure 6 distribution of total efficiency gap

Finally, the optimal solution for an inefficient DMUo can now be expressed by means of (4.8) - (4.11).

$$x_{mo}^{**} = x_{mo} - d_{mo}^{x*} - s^{-**}, \quad m \in D \tag{4.8}$$

$$y_{so}^{**} = y_{so} + d_{so}^{y*} + s^{+**}, \quad s \in D \tag{4.9}$$

$$x_{mo}^{**} = x_{mo}, \quad m \in ND \tag{4.10}$$

$$y_{so}^{**} = y_{so}, \quad s \in ND \tag{4.11}$$

The slacks $s^{-**}, m \in ND$ and s^{+**}, $s \in ND$ are not incorporated in (4.10) and (4.11) because these factors are ‘fixed ’or ‘non-discretionary’ inputs and outputs, in a way similar to the Banker and Morey (1986) model outlined above. This approach will hereafter be described as the DFM-FF approach.

5. Context-Dependent DEA

The Context-Dependent (CD hereafter) model can obtain efficient frontiers in different levels, and can yield a level-by-level improvement projection. The CD model is formulated below.

Let $J^l = \{DMU_j, j = 1, \cdots, J\}$ be the set of all J DMUs. We interactively define $J^{l+1} = J^l - E^l$ where $E^l = \{DMU_k \in J^l \mid \theta^*(l,k)\} = 1$ and $\theta^*(l,k)$ is the optimal value by using formula (2.1).

When l = 1, it becomes the original CCR model and the DMUs in set E1 define the first-level efficient frontier. When l = 2, it gives the second-level efficient frontier after the exclusion of the first-level efficient DMUs. And so on. In this manner, we identify several levels of efficient frontiers. We call El the lth-level efficient frontier. The following algorithm accomplishes the identification of these efficient frontiers.

Step 1: Set l = 1. Evaluate the entire set of DMUs, J1,. We obtain then the first-level efficient DMUs for set E1 (the first-level efficient frontier).

Step 2: Exclude the efficient DMUs from future DEA runs. $J^{l+1} = J^l - E^l$ (If $J^{l+1} = \phi$, then stop.)

Step 3: Evaluate the new subset of "inefficient" DMUs. We obtain then a new set of efficient DMUs E^{l+1} (the new efficient frontier).

Step 4: Let $l = l$ + 1. Go to step 2.

Stopping rule: $J^{l+1} = \phi$, the algorithm is terminated.

A visual presentation of the CD model is given in Figure 7.

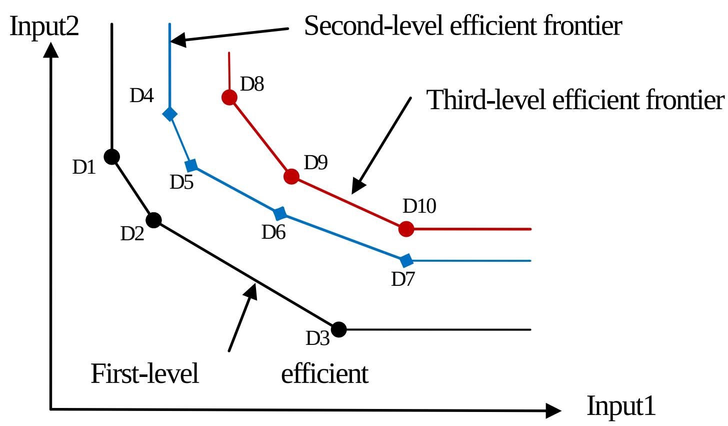

Figure 7 Illustration of the CD model

6. Stepwise-DFM-FF Model in DEA

We propose a Stepwise DFM-FF model that is integrated with a DFM-FF and CD model.

Any efficiency-improving projection model which includes the standard CCR projection supplemented with the DFM-projection is always directed towards achieving "full efficiency". This strict condition may not always be easy to achieve in reality. Therefore, in this section we will develop a new efficiency improving projection model, which aims to integrate with CD model and DFM-FF approach, the "Stepwise Distance Friction Minimization Fixed Factor" (Stepwise DFM-FF hereafter) model. It can yield a stepwise efficiency improving projection incorporating fixed inputs and outputs factor that depends on l -level efficient frontiers (l-level DFM projection), as shown in Figure 8.

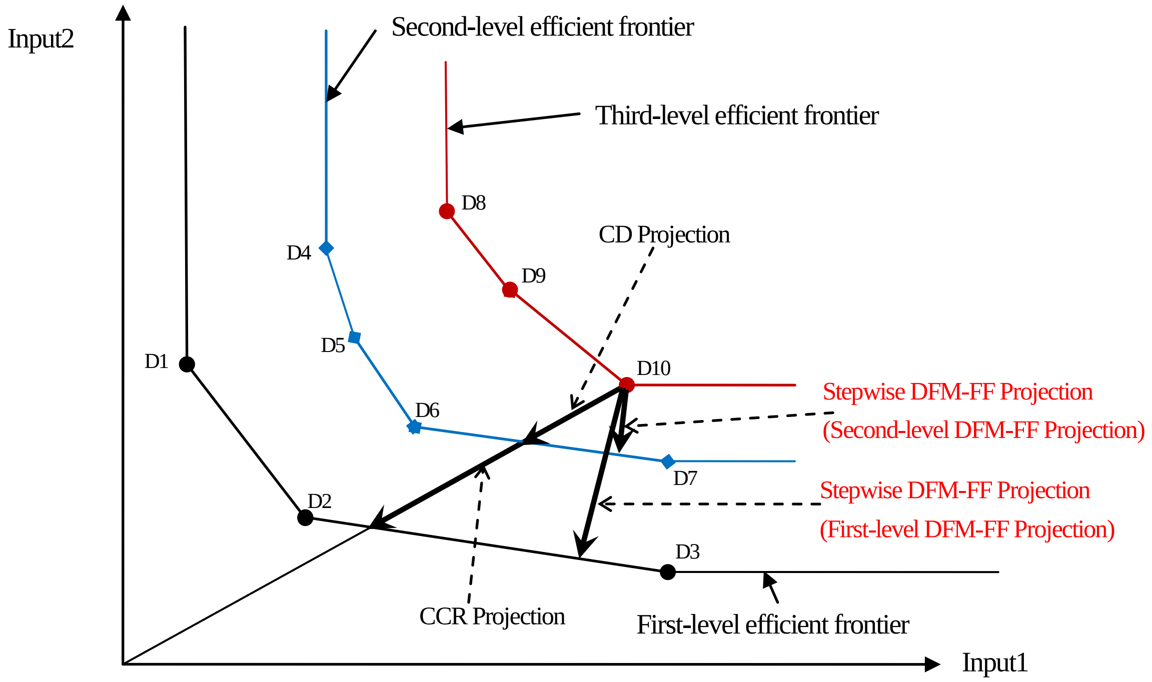

Figure 8 Illustration of the Stepwise DFM-FF model

For example, a second-level DFM-FF projection for DMU10 (D10) aims to position DMU10 on a second-level efficient frontier. And a first-level DFM-FF projection is just equal to a DFM-FF projection (4.1)-(4.7). We notice here that the second-level DFM-FF projection is easier to achieve than a first-level DFM-FF projection. A stepwise-DFM-FF model can yield a more practical and realistic efficiency improving projection than a CCR Projection or a DFM-FF Projection.

The advantage of the Stepwise DFM-FF model is also that it yields an outcome on a l-level efficient frontier that is as close as possible to the DMU's input and output profile (see Figure 8).

7. Application of a Stepwise DFM-FF Model to Airport Efficiency Management

7.1 Database and analysis framework

In our empirical work, we use input and output data for a set of 25 airports in Japan. The DMUs used in our analysis are listed in Table 1.

Table 1 A listing of DMUs

No.	DMU	No.	DMU
1	Tokyo Haneda	14	Kochi
2	Osaka Itami	15	Kitakyushu
3	New Chitose (Sapporo)	16	Nagasaki
4	Fukuoka	17	Kumamoto
5	Okinawa	18	Ooita
6	Wakkanai	19	Miyazaki
7	Kushiro	20	Kagoshima
8	Hakodate	21	Okadama
9	Sendai	22	Komathu
10	Niigata	23	Miho
11	Hiroshima	24	Tokushima
12	Takamatsu	25	Misawa
13	Matsuyama		

In this study we use the following inputs and outputs:

- Input:

  (I) Operating cost (except employment cost) (in 2007);

  (I) Employment cost (in 2007);

  (IF) Total runway length (in 2007);

- Output:

  (O) Operating revenues (in 2007);

All data were obtained from the "revenue and expenditure 2007" in Ministry of Land, Infrastructure, Transport and Tourism in Japan. Some inputs or outputs may have a fixed character, implying that they cannot be changed in strategies to improve efficiency. This is an element that has to be taken into account in the efficiency analysis. In the present context, the Total runway length may be interpreted as a fixed factor. A least in the short run, this factor cannot easily be changed.

In our application, we first applied the standard CCR model, while next the results were used to determine the CCR and DFM-FF projections. Additionally, we applied the CD model, and then the results were used to determine the CD and Stepwise DFM-FF projections. Finally, these various results were mutually compared.

7.2 Efficiency evaluation based on the CCR model

The efficiency evaluation results for the 25 airports based on the CCR model is given in Figure 9. From Figure 9, it can be seen that Tokyo Haneda, Osaka Itami and Komathu are efficiently-operating Airports. On the other hand, Wakkanai, Kushiro, Okadama and Miho has a low efficiency. It is noteworthy that Wakkanai, Kushiro, Okadama are in Hokkaido prefecture where is a most north part of Japan.

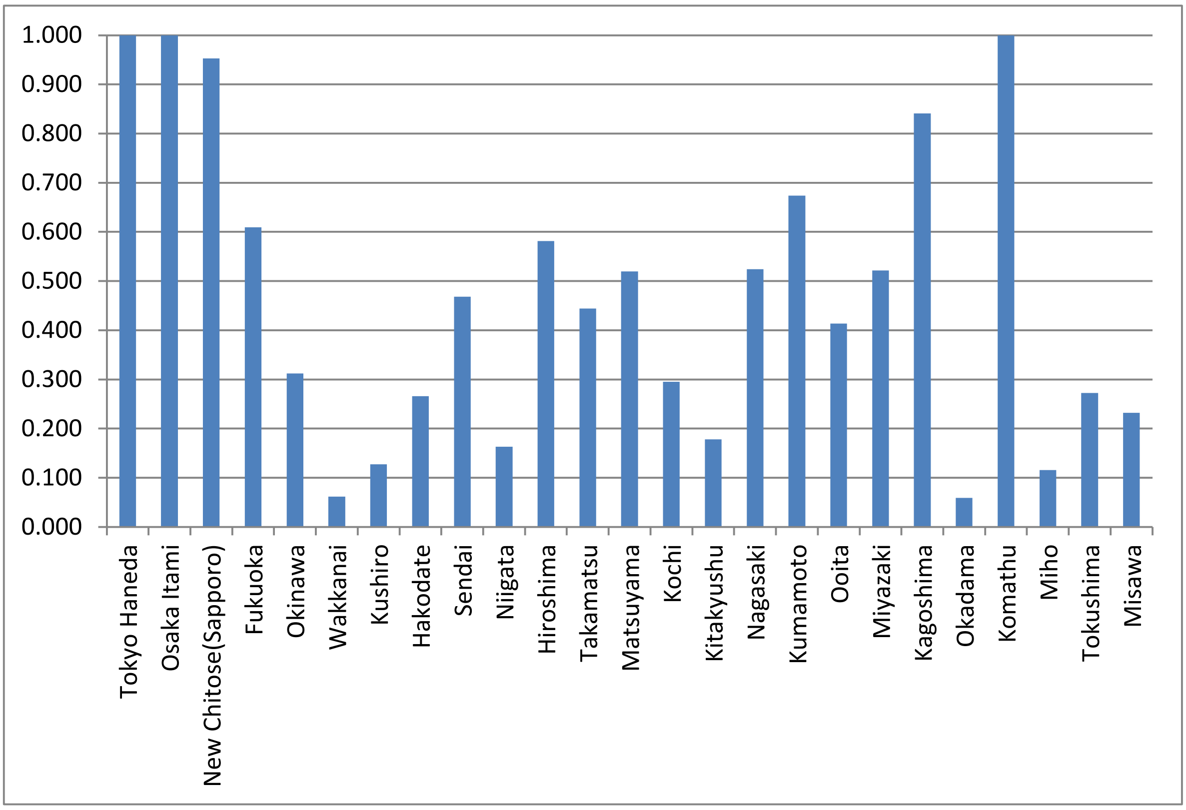

Figure 8 Efficiency score based on the CCR model

7.3 Direct efficiency improvement projection based on the CCR and DFM models

The direct efficiency improvement projection results based on the CCR and DFM model for inefficient airports are presented in Table 2.

Table 2 Direct efficiency-improvement projection results of the CCR and DFM model

DMU	Score	CCR-I model		DFM-FF model	
		Score(θ**)		Score(θ**)	
I/O	Data	Difference	%	Difference $d_{io}^{x*}-s^{-**}$ $d_{ro}^{y*}+s^{+**}$	%
New Chitose(Sapporo)	0.953	1.000		1.000	
(I)OC	6644	-311.5	-4.7%	-169.3	-2.5%
(I)EC	653	-208.1	-31.9%	-197.8	-30.3%
(IF)TRL	6000	-281.3	-4.7%	0.0	0.0%
(O)OR	9562	0.0	0.0%	243.7	2.5%
Fukuoka	0.609	1.000		1.000	
(I)OC	15577	-7266.5	-46.7%	-1936.4	-12.4%
(I)EC	629	-325.0	-51.7%	-129.9	-20.7%
(IF)TRL	2800	-1094.1	-39.1%	0.0	0.0%
(O)OR	10436	0.0	0.0%	6693.4	64.1%
Okinawa	0.312	1.000		1.000	
(I)OC	8084	-5564.0	-68.8%	-4913.1	-60.8%
(I)EC	624	-479.0	-76.8%	0.0	0.0%
(IF)TRL	3000	-2064.8	-68.8%	0.0	0.0%
(O)OR	3440	0.0	0.0%	2090.7	60.8%
Wakkanai	0.061	1.000		1.000	
(I)OC	988	-927.3	-93.9%	-988.0	-100.0%
(I)EC	109	-104.6	-95.9%	0.0	0.0%
(IF)TRL	2200	-2064.7	-93.9%	0.0	0.0%
(O)OR	107	0.0	0.0%	122.3	114.3%
Kushiro	0.127	1.000		1.000	
(I)OC	1772	-1546.7	-87.3%	-1610.6	-90.9%
(I)EC	165	-148.9	-90.3%	0.0	0.0%
(IF)TRL	2500	-2182.1	-87.3%	0.0	0.0%
(O)OR	362	0.0	0.0%	329.0	90.9%
Hakodate	0.266	1.000		1.000	
(I)OC	1982	-1454.9	-73.4%	-1335.9	-67.4%
(I)EC	148	-110.3	-74.5%	0.0	0.0%
(IF)TRL	3000	-2202.2	-73.4%	0.0	0.0%
(O)OR	857	0.0	0.0%	577.6	67.4%
Sendai	0.468	1.000		1.000	
(I)OC	2143	-1139.9	-53.2%	-911.6	-42.5%
(I)EC	346	-273.4	-79.0%	-253.2	-73.2%
(IF)TRL	4200	-2234.1	-53.2%	0.0	0.0%
(O)OR	1716	0.0	0.0%	730.0	42.5%
Niigata	0.163	1.000		1.000	
(I)OC	2594	-2171.0	-83.7%	-2359.5	-91.0%
(I)EC	131	-109.6	-83.7%	-63.8	-48.7%
(IF)TRL	3814	-3192.0	-83.7%	0.0	0.0%
(O)OR	651	0.0	0.0%	550.9	84.6%
Hiroshima	0.582	1.000		1.000	
(I)OC	1780	-744.8	-41.8%	-536.4	-30.1%
(I)EC	221	-146.6	-66.3%	-129.8	-58.7%
(IF)TRL	3000	-1255.3	-41.8%	0.0	0.0%
(O)OR	1717	0.0	0.0%	517.4	30.1%
Takamatsu	0.444	1.000		1.000	
(I)OC	998	-554.9	-55.6%	-469.5	-47.0%
(I)EC	114	-81.4	-71.4%	0.0	0.0%
(IF)TRL	2500	-1389.9	-55.6%	0.0	0.0%
(O)OR	804	0.0	0.0%	378.3	47.0%
Matsuyama	0.519	1.000		1.000	
(I)OC	1468	-705.6	-48.1%	-532.7	-36.3%
(I)EC	133	-78.2	-58.8%	-63.9	-48.1%
(IF)TRL	2500	-1201.7	-48.1%	0.0	0.0%
(O)OR	1267	0.0	0.0%	459.8	36.3%

DMU	Score	CCR-I model		DFM-FF model	
		Score(θ**)		Score(θ**)	
I/O	Data	Difference	%	Difference $d_{io}^{x*}-s^{-**}$ $d_{ro}^{y*}+s^{+**}$	%
Kochi	0.295	1.000		1.000	
(I)OC	1226	-863.9	-70.5%	-806.7	-65.8%
(I)EC	133	-106.7	-80.2%	0.0	0.0%
(IF)TRL	2500	-1761.5	-70.5%	0.0	0.0%
(O)OR	625	0.0	0.0%	411.2	65.8%
Kitakyushu	0.178	1.000		1.000	
(I)OC	2563	-2106.3	-82.2%	-2229.0	-87.0%
(I)EC	130	-106.8	-82.2%	-34.3	-26.4%
(IF)TRL	2500	-2054.5	-82.2%	0.0	0.0%
(O)OR	662	0.0	0.0%	515.4	77.9%
Nagasaki	0.524	1.000		1.000	
(I)OC	1282	-610.3	-47.6%	-505.9	-39.5%
(I)EC	118	-67.6	-57.3%	0.0	0.0%
(IF)TRL	4200	-1999.6	-47.6%	0.0	0.0%
(O)OR	1317	0.0	0.0%	519.7	39.5%
Kumamoto	0.674	1.000		1.000	
(I)OC	1294	-422.1	-32.6%	-296.0	-22.9%
(I)EC	120	-56.2	-46.9%	-45.6	-38.0%
(IF)TRL	3000	-978.6	-32.6%	0.0	0.0%
(O)OR	1551	0.0	0.0%	354.7	22.9%
Ooita	0.414	1.000		1.000	
(I)OC	1211	-710.2	-58.6%	-615.7	-50.8%
(I)EC	114	-77.2	-67.7%	0.0	0.0%
(IF)TRL	3000	-1759.3	-58.6%	0.0	0.0%
(O)OR	906	0.0	0.0%	460.7	50.8%
Miyazaki	0.522	1.000		1.000	
(I)OC	1716	-820.8	-47.8%	-607.8	-35.4%
(I)EC	136	-72.1	-53.0%	-55.1	-40.5%
(IF)TRL	2500	-1195.7	-47.8%	0.0	0.0%
(O)OR	1446	0.0	0.0%	512.2	35.4%
Kagoshima	0.841	1.000		1.000	
(I)OC	1608	-255.3	-15.9%	-156.4	-9.7%
(I)EC	366	-268.3	-73.3%	-260.6	-71.2%
(IF)TRL	3000	-476.2	-15.9%	0.0	0.0%
(O)OR	2290	0.0	0.0%	222.8	9.7%
Okadama	0.059	1.000		1.000	
(I)OC	597	-561.8	-94.1%	-597.0	-100.0%
(I)EC	77	-74.4	-96.6%	0.0	0.0%
(IF)TRL	1500	-1411.4	-94.1%	0.0	0.0%
(O)OR	64	0.0	0.0%	75.6	118.2%
Miho	0.115	1.000		1.000	
(I)OC	1650	-1473.2	-89.3%	-1333.0	-80.8%
(I)EC	56	-49.5	-88.5%	-44.4	-79.3%
(IF)TRL	2500	-2463.7	-98.6%	0.0	0.0%
(O)OR	222	0.0	0.0%	176.0	79.3%
Tokushima	0.273	1.000		1.000	
(I)OC	1367	-994.3	-72.7%	-547.8	-40.1%
(I)EC	55	-40.0	-72.7%	-36.7	-66.7%
(IF)TRL	2500	-2292.8	-91.7%	0.0	0.0%
(O)OR	497	0.0	0.0%	284.0	57.2%
Misawa	0.232	1.000		1.000	
(I)OC	292	-224.2	-76.8%	-182.0	-62.3%
(I)EC	88	-82.8	-94.1%	-79.6	-90.4%
(IF)TRL	3050	-2774.8	-91.0%	0.0	0.0%
(O)OR	143	0.0	0.0%	89.1	62.3%

In Table 2, it appears that the empirical ratios of change in the DFM projection are smaller than those in the CCR projection, as was expected. In Table 2, this particularly applies to Okinawa, Kushiro, Hakodate, Niigata, Takamatsu, Kochi, Kitakyushu, Nagasaki, Ooita and Tokushima which are apparently non-slack type (i.e. s^{-**} and s^{+**} are zero) Airports. The DFM-FF projection involves both input reduction and output increase, and, clearly, the DFM-FF projection does not involve a uniform ratio, because this model looks for the optimal input reduction (i.e., the shortest distance to the frontier, or distance friction minimization). For instance, the CCR projection shows that Tokushima should reduce the Operating cost and the Employment cost by 72.7% and the Total runway length by 91.7% in order to become efficient. On the other hand, the DFM-FF results show that a reduction in the Operating cost of 40.1% and the Employment cost of 72.7%, and an increase in the Operating revenues of 57.2% are required to become efficient. This result shows that indeed the DFM-FF projection can be generated as a solution where Total runway length is fixed. Apart from the practicality of such a solution, the models show clearly that a different – and perhaps more efficient – solution is available than the standard CCR projection to reach the efficiency frontier.

7.4 Stepwise efficiency improvement projection based on the CD and Stepwise DFM-FF models

The efficiency improvement projection results for the nearest upper level efficient frontier based on the CD and Stepwise DFM-FF model for inefficient airports are presented in Table 3.

In Table 3, it appears that the ratios of change in the Stepwise DFM-FF projection are smaller than those in the CD projection, as was expected. In Table 3, this particularly applies to Kumamoto, Miyazaki, Hiroshima, Matsuyama, Ooita, Hakodate, and Kochi, which are non-slack type (i.e. s^{-**} and s^{+**} are zero) corporations. Apart from the practicality of such a solution, the models show clearly that a different – and perhaps more efficient – solution is available than the CD projection to reach the efficiency frontier.

The Stepwise-DFM-FF model is able to present a more realistic efficiency-improvement plan, which we compared with the results of Tables 2 and 3. For instance, the DFM-FF results in Table 2 show that Hakodate should reduce the Operating cost by 67.4%, an increase in the Operating revenues of 67.4 per cent in order to become efficient. On the other hand, the Stepwise DFM-FF results in Table 3 show that a reduction in employment cost of 11.1%, and an increase in the Operating revenues of 11.1% are required to become efficient. Note also that Total runway length is interpreted application as a fixed factor in both DFM-FF and Stepwise DFM-FF model.

Table 3 Efficiency-improvement projection results for nearest upper level efficient frontier

			CD model		Stepwise DFM-FF model	
	DMU	Score	Score(θ**)		Score(θ**)	
	I/O	Data	Difference	%	Difference $d_{io}^{x*}-s^{-**}$ $d_{ro}^{y*}+s^{+**}$	%
E3	Okinawa	0.487	1.000		1.000	
	(I)OC	8084	-4145.6	-51.3%	-4004.1	-49.5%
	(I)EC	624	-404.6	-64.9%	-277.8	-44.5%
	(IF)TRL	3000	-1538.5	-51.3%	0.0	0.0%
	(O)OR	3440	0.0	0.0%	1703.9	49.5%
	Kumamoto	0.878	1.000		1.000	
	(I)OC	1294	-158.1	-12.2%	0.0	0.0%
	(I)EC	120	-14.7	-12.2%	-8.7	-7.2%
	(IF)TRL	3000	-2053.0	-68.4%	0.0	0.0%
	(O)OR	1551	0.0	0.0%	100.9	6.5%
	Miyazaki	0.710	1.000		1.000	
	(I)OC	1716	-497.2	-29.0%	0.0	0.0%
	(I)EC	136	-39.4	-29.0%	-26.0	-19.1%
	(IF)TRL	2500	-1689.0	-67.6%	0.0	0.0%
	(O)OR	1446	0.0	0.0%	245.0	16.9%
	Kagoshima	0.990	1.000		1.000	
	(I)OC	1608	-16.8	-1.1%	-8.5	-0.5%
	(I)EC	366	-209.6	-57.3%	-208.8	-57.0%
	(IF)TRL	3000	-1563.1	-52.1%	0.0	0.0%
	(O)OR	2290	0.0	0.0%	12.0	0.5%
E4	Hiroshima	0.912	1.000		θ^{**}=1.000	
	(I)OC	1780	-155.9	-8.8%	0.0	0.0%
	(I)EC	221	-19.4	-8.8%	-17.7	-8.0%
	(IF)TRL	3000	-262.7	-8.8%	0.0	0.0%
	(O)OR	1717	0.0	0.0%	113.4	6.6%
	Matsuyama	0.893	1.000		1.000	
	(I)OC	1468	-156.6	-10.7%	0.0	0.0%
	(I)EC	133	-14.2	-10.7%	-14.7	-11.1%
	(IF)TRL	2500	-266.6	-10.7%	0.0	0.0%
	(O)OR	1267	0.0	0.0%	108.5	8.6%
	Nagasaki	0.864	1.000		1.000	
	(I)OC	1282	-183.2	-14.3%	-102.8	-8.0%
	(I)EC	118	-16.1	-13.7%	-8.6	-7.3%
	(IF)TRL	4200	-1652.6	-39.4%	0.0	0.0%
	(O)OR	1317	0.0	0.0%	96.5	7.3%
E5	Sendai	0.821	1.000		1.000	
	(I)OC	2143	-383.8	-17.9%	-220.3	-10.3%
	(I)EC	346	-137.3	-39.7%	-126.7	-36.6%
	(IF)TRL	4200	-752.1	-17.9%	0.0	0.0%
	(O)OR	1716	0.0	0.0%	176.4	10.3%
	Takamatsu	0.808	1.000		1.000	
	(I)OC	998	-191.5	-19.2%	-112.1	-11.2%
	(I)EC	114	-27.2	-23.9%	-24.3	-21.3%
	(IF)TRL	2500	-479.7	-19.2%	0.0	0.0%
	(O)OR	804	0.0	0.0%	90.3	11.2%
	Ooita	0.785	1.000		1.000	
	(I)OC	1211	-259.9	-21.5%	-291.3	-24.1%
	(I)EC	114	-24.5	-21.5%	0.0	0.0%
	(IF)TRL	3000	-643.9	-21.5%	0.0	0.0%
	(O)OR	906	0.0	0.0%	127.8	14.1%
	Tokushima	0.810	1.000		1.000	
	(I)OC	1367	-883.2	-64.6%	-832.3	-60.9%
	(I)EC	55	-10.5	-19.0%	-5.8	-10.5%
	(IF)TRL	2500	-915.0	-36.6%	0.0	0.0%
	(O)OR	497	0.0	0.0%	52.3	10.5%

			CD		Stepwise DFM-FF model	
	DMU	Score	Score(θ**)		Score(θ**)	
	I/O	Data	Difference	%	Difference $d_{io}^{x*}-s^{-**}$ $d_{ro}^{y*}+s^{+**}$	%
E6	Hakodate	0.865	1.000		1.000	
	(I)OC	1982	-917.4	-46.3%	0.0	0.0%
	(I)EC	148	-20.0	-13.6%	-16.5	-11.1%
	(IF)TRL	3000	-406.4	-13.6%	0.0	0.0%
	(O)OR	857	0.0	0.0%	95.3	11.1%
	Kochi	0.736	1.000		1.000	
	(I)OC	1226	-449.0	-36.6%	0.0	0.0%
	(I)EC	133	-35.1	-26.4%	-31.7	-23.8%
	(IF)TRL	2500	-659.4	-26.4%	0.0	0.0%
	(O)OR	625	0.0	0.0%	149.0	23.8%
E7	Kitakyushu	0.927	1.000		1.000	
	(I)OC	2563	-1032.0	-40.3%	-911.3	-35.6%
	(I)EC	130	-15.7	-12.1%	-6.7	-5.1%
	(IF)TRL	2500	-182.6	-7.3%	0.0	0.0%
	(O)OR	662	0.0	0.0%	52.2	7.9%
	Misawa	0.961	1.000		1.000	
	(I)OC	292	-11.5	-3.9%	-5.9	-2.0%
	(I)EC	88	-57.6	-65.4%	-57.0	-64.7%
	(IF)TRL	3050	-2478.0	-81.3%	0.0	0.0%
	(O)OR	143	0.0	0.0%	2.9	2.0%
E8	Niigata	0.976	1.000		1.000	
	(I)OC	2594	-73.6	-2.8%	-42.8	-1.7%
	(I)EC	131	-3.2	-2.4%	-1.6	-1.2%
	(IF)TRL	3814	-1355.5	-35.5%	0.0	0.0%
	(O)OR	651	0.0	0.0%	7.9	1.2%
E9	Kushiro	0.848	1.000		1.000	
	(I)OC	1772	-329.6	-18.6%	-71.7	-4.0%
	(I)EC	165	-92.2	-55.9%	-79.1	-48.0%
	(IF)TRL	2500	-379.2	-15.2%	0.0	0.0%
	(O)OR	362	0.0	0.0%	64.7	17.9%
	Miho	0.798	1.000		1.000	
	(I)OC	1650	-765.4	-46.4%	-665.9	-40.4%
	(I)EC	56	-11.3	-20.2%	-6.3	-11.3%
	(IF)TRL	2500	-1199.4	-48.0%	0.0	0.0%
	(O)OR	222	0.0	0.0%	25.0	11.3%
E10	Wakkanai	0.530	1.000		1.000	
	(I)OC	988	-464.2	-47.0%	-303.4	-30.7%
	(I)EC	109	-60.2	-55.3%	-45.3	-41.5%
	(IF)TRL	2200	-1461.0	-66.4%	0.0	0.0%
	(O)OR	107	0.0	0.0%	32.9	30.7%
E11	Okadama	0.990	1.000		1.000	
	(I)OC	597	-6.0	-1.0%	-3.0	-0.5%
	(I)EC	77	-11.8	-15.3%	-11.5	-14.9%
	(IF)TRL	1500	-184.1	-12.3%	0.0	0.0%
	(O)OR	64	0.0	0.0%	0.3	0.5%

The Stepwise DFM-FF model provides the policy decision-maker with practical and transparent solutions that are available in the DFM-FF projection to reach the nearest upper level efficiency frontier.

These results offer a meaningful contribution to decision support and planning for the efficiency improvement of Airport operations.

In conclusion, this Stepwise DFM-FF model may become a policy vehicle that may have great added value for decision making and planning of both public and private actors.

7. Conclusion

In this paper we have presented a new methodology, the Stepwise DFM-FF model, which is integrated with a DFM-FF and CD model. The new method minimizes the distance friction for each input and output separately. As a result, the reductions in inputs and increases in outputs do necessarily reach an efficiency frontier that is smaller than in the standard model. Furthermore, the new model can incorporate a fixed factor, and then it could be adapt a realistic circumstance and requirement in an efficiency improvement projection, this offers more flexibility for the operational management of an organization. In addition, the stepwise projection allows DMUs to include various levels of ambition regarding the ultimate performance in their strategic judgment. In conclusion, our Stepwise DFM-FF model is able to present a more realistic efficiency-improvement plan, and may thus provide a meaningful contribution to decision making and planning for efficiency improvement of relevant agents.

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